

FRAMEWORK FOR UNDERSTANDING THE RELATIONSHIP BETWEEN LEAN
AND SAFETY IN CONSTRUCTION

A Thesis

by

RAMYA PRAKASH

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2010

Major Subject: Construction Management

Framework for Understanding the Relationship between Lean and Safety
in Construction

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Approved by:

Chair of Committee,	José L.Fernández-Solís
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Head of Department,	Joe Horlen

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ABSTRACT

Framework for Understanding the Relationship between Lean and Safety
in Construction. (May 2010)

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Chair of Advisory Committee: Dr. José L.Fernández-Solís

Lean construction borrows concepts from lean manufacturing and Toyota Production System in order to eliminate waste and add value to the construction process. Manufacturing processes utilizing lean principles have matured and developed a clear understanding of the relation between lean and safety. Because lean in construction is a relatively new phenomenon, there is not a completely developed understanding of how lean practices affect safety in construction. The Lean Construction Institute and the Academic Forum for Lean Construction has recently targeted this area for focused research. Since all safety incidents imply waste in time and resources, lean and safety have a common ground in the minimization of waste.

This thesis researches the common ground of lean and safety in waste minimization and proposes a framework for understanding their relationship. This thesis also critically analyzes lean and safety principles to form an insight to the relationship between lean theories as well as practices and safety issues reported in construction literature. Further, literature also revealed the safety strategies and checklists that companies typically incorporate in their program. A comparative analysis of lean and

safety is employed to understand their relations in a better way. This framework establishes that lean and safety have a strong relationship in the context of construction. Future work is needed to show that lean practices indeed strongly affect safety by reducing the number of incidents.

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TABLE OF CONTENTS

	Page
ABSTRACT	iii
ACKNOWLEDGEMENTS	v
TABLE OF CONTENTS	vi
LIST OF FIGURES	vii
LIST OF TABLES	viii
1. INTRODUCTION	1
1.1 Research Questions	5
1.2 Research Objectives	6
2. LITERATURE REVIEW	7
2.1 Lean... ..	10
2.2 Safety	12
3. RESEARCH METHODS	16
3.1 Data Collection	17
3.2 Data Analysis	26
3.3 Data Interpretation	34
3.4 Case Studies Reviewed	37
4. FINDINGS	42
5. CONCLUSIONS	45
5.1 Conclusions	45
5.2 Future Work	46
REFERENCES	47
VITA	52

LIST OF FIGURES

FIGURE	Page
1 Common element between lean, safety	5
2 Three zones of risk	8
3 Overview of the safety, planning and control process	9
4 Framework showing the relationship of the lean methods and safety programs	41
5 Chart showing the relationship framework percentage breakdown	42
6 Safety impact	43
7 Lean utilization	44

LIST OF TABLES

TABLE	Page
1 Exploration of lean methods objectives.	28
2 Safety impact of lean methods during lean project delivery phases.	32

1. INTRODUCTION

Lean construction borrows lean manufacturing and Toyota Production System concepts (Koskela 1992) in order to eliminate waste and add value to the construction process. Manufacturing processes utilizing lean principles have matured and developed a clear understanding of the relation between lean and safety (Williams and Robert 2005). Safety is related to reducing the number of accidents on a job site and is now tending to achieve zero accidents on construction sites (Liska et al. 1993). This is seen as a way to reduce the waste in resources and time that accidents cause, which has to be eliminated in order to function effectively. Hence it is a necessity to discover the possibility of integrating lean and safety principles at all levels of construction.

Safety has historically been treated as a separate subject, which could be improved in isolation from production. However, safety is an integral part of every production process, not something that is thought of later or seen as an addin. Safety is important as it depends on every action, material and people involved (Nahmens and Ikuma 2009). The implementation of lean thinking and techniques encourages minimizing material in work area, an orderly , clean workplace and systematic work flow. In the industry the use of lean construction tools like Last Planner System claim to reduce accident rates (Ballard and Howell 1994).

This thesis follows the style of *Journal of Construction Engineering and Management*.

The dynamic, unpredictable and often hostile construction tasks and environments combined with high production pressures and workload create high likelihood for errors. For these mentioned reasons coordination amongst crew and communication are essential for effective and safe performance of construction crews (Mitropoulos et al. 2007). The crews that used lean construction tools, including Last Planner, had about 45 % lower accident rates than crews in the same organization performing similar sort of work who did not use the Last Planner system. (Thomassen et al. 2003). These examples suggest that when the principles of safety and lean are combined they enhance improvement of the workplace. The significant characteristics revealed by the lean tools and safety practices, is instrumental in finding a common factor to establish a relationship between the two theories.

Lean in construction is a relative new phenomenon introduced by Koskela in the UK (1992). Ballard in the USA (2000) pioneered promoting lean in construction. However, unlike in manufacturing, construction does not have completely developed understanding of how lean practices affect safety. The Lean Construction Institute and the Academic Forum for Lean Construction has recently targeted this area for focused research. (Lean Construction Institute Academic Forum 2009)

The systemic nature of the construction industry (Fernandez-Solis 2009) of the United States is characterized by employing high technology in the design and planning, but in the field practices it is characterized by low productivity, cost overruns, schedule overruns, shortage of skilled labor and high incident of safety issues (when compared

with other industries) (Nahmens and Ikuma 2009). In particular, the lack of safety is seen as one of the chronic problems in construction.

The total injury and illness incidence rates for prefabricated wood manufacturing in the U.S. ranged from 9.5 to 14.3 per 100 workers over the past 5 years. Residential construction incidence rate is approximately 5 per 100 workers (Bureau of labor statistics 2008). Injury rates for both sectors are higher than the national average of 4.2 injuries per 100 workers (Nahmens and Ikuma 2009). The traditional construction process of the industry pushes the client into an often prolonged development process where risk and uncertainty are prevalent (Garnett et al. 1998). This justifies an increased focus on improving safety in all facets of construction.

Problems in the construction industry also include poor communication between teams, lack of documentation, deficient in making timely decisions and negative iterations of design (Ballard and Koskela 1998). This implies there is a work system needs to be developed to achieve high levels of productivity and safety as Mitropoulos et al. (2005) states. Standardizing, systematizing and regularizing production can be expected to lead to better safety as side effect (Kobayashi 1990). Nahmens and Ikuma (2009) in their research findings question if “implementation of lean principles result in improved safety.” It also leads to the question if these theories can be combined to develop a framework. Main et al, (2008) state to “demonstrate why safety and lean concepts need to be addressed concurrently.”

Risk in construction is the probability of occurrence of an incident in form of an accident like fatality, injury and the severity of expected outcome (ISI 2000). Risks

could also be termed as potential hazards on a jobsite. Hazard is a condition, which if released can lead to injury unless the worker is able to detect and avoid it without increasing exposure (Howell et al. 2002).

Lean thinking suggests that activities undertaken to promote occupational safety and health in construction can be improved – that the waste produced or generated can be identified and removed and the negative impacts on process flow can be minimized. Since all safety incidents imply waste in time and resources, lean and safety have a common ground in the minimization of waste and risk. The accidents that occur during the process of construction and lead to injury are considered as a waste. Occupational Safety and Health Administration (OSHA) administered the workers health in different occupations and thus laid down guidelines and specifications that have to be followed on the jobsite. Through this it is understood that the element of risk and uncertainty acts in cohesion with both lean and safety. Lean is defined as reduction of waste in processes (Koskela 1992) and the goal of safety is to reduce incidents on the jobsite, which are a form of waste in terms of resources such as time and material. Therefore a common relation can be identified amongst the four related elements of lean, safety, waste reduction and safety reduction. Waste and Incidents are reduced by minimizing risks and uncertainty. The relationship defining the reliance of lean, safety, waste reduction and incidence reduction on each other is represented in Fig 1.

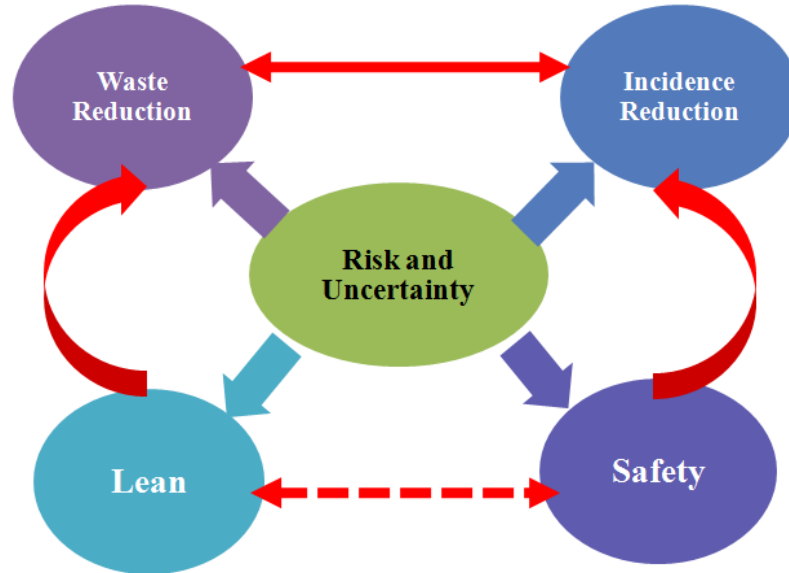


Fig.1. Common element between lean, safety.

1.1 RESEARCH QUESTIONS

Safety and lean aims at similar goals in making the construction process faster, better and safer (Main et al. 2008). This thesis intends to answer the basic questions of “is there a relationship between lean and safety principles to help in reduction of waste and incidents.” Lean thinking is based on elimination of waste and value addition. Lean methods help in reducing variability in construction processes by shifting to process centered thinking (Howell 1999). Safety concurrently takes measures to make the work area safe and reduce injuries. The literature studied explores the aspects of the research problem and provides an insight into various works accomplished in areas of lean and safety in the construction industry.

1.2 RESEARCH OBJECTIVES

This research tracks lean thinking and ideologies that are prevalent in various cases. The primary objective of this research is to understand the relationship of lean and safety through risk and uncertainty reduction. To represent this, a qualitative analysis of lean methods and safety practices in the construction industry will be derived. Relations between the lean methods and safety practices will also be studied and impacts of safety on the lean methods will be analyzed. A framework that expresses the relationship of lean and safety theories will yield towards understanding the relations individually. This will provide a larger picture on the association of lean and safety and study the common grounds used in the minimization of waste and risk.

2. LITERATURE REVIEW

Extensive studies have been done to explore the synergy between safety and lean in construction. Prior to combining these two principles it is important to know the significance and the properties each bring to the common module. Therefore literature studied explores topics of lean principles, how they came into existence, the methods used in lean construction/manufacturing, safety, accidents, and safety programs. Recent papers have discussed opportunities for applying Cognitive Systems Engineering (CSE) with a perspective on safety ideas in construction industry. Cognitive systems engineering is based on flexibility, learning and awareness (Saurin et al. 2008), which are symbiotic with lean as they add value to the process. This was used owing to the fact of the dynamism and complexity of the construction sites and it also provides high level guidelines on work system design which makes it easier to adapt in different industries. Based on behavior based approaches, Howell et al. (2002), Salem et al. (2007) reviewed traditional safety management best practices, and concluded that they were ineffective to make workers capable of performing at the edge of loss of control. This theory is represented in Fig.2. where there are three zones of risk; safe zone, hazard zone and a loss of control zone. This model suggests that the safe zone can be increased by planning and operations. The hazard zone is where workers can identify the risk and latent hazard beyond which the boundaries of work become unsafe. Loss of control zones directs the management to take measures to minimize the risk caused by it, thus minimizing the zone.

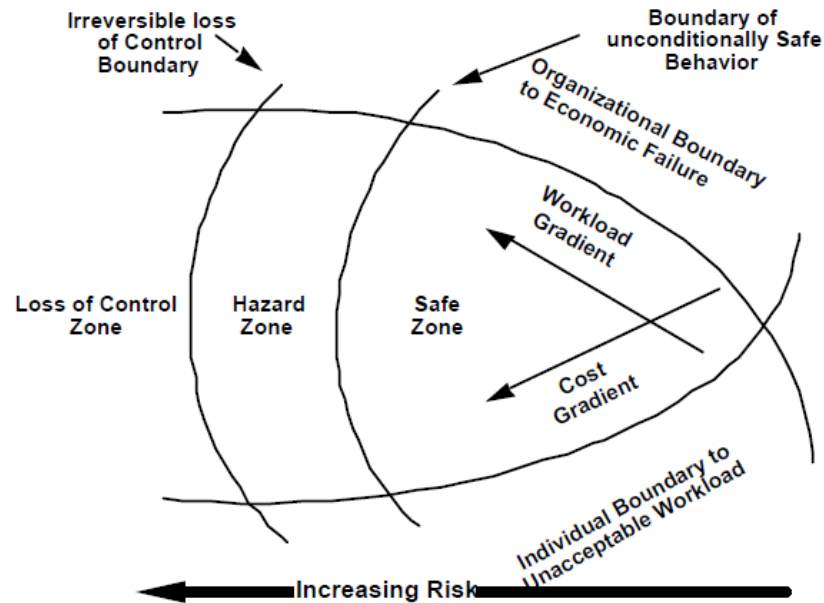


Fig.2. Three zones of risk. (Howell et al. 2002)

Abdelhamid et al. (2003) conducted an application of signal detection theory as a mechanism to sharpen worker's sensitivity to hazard identification – this is particularly important in the edge of loss of control. Saurin et al. (2006) carried out an analysis of the frequency of errors and violations in five construction sites. Also, Saurin et al. (2008) extended the discussion of Howell et al. (2002) on the applicability of CSE to construction safety based on empirical data. CSE theory in Saurian's paper was helpful in improving safety practices related to, process transparency, planning, performance migrations, accident investigations and identifying risks. These practices were chosen as they were important in construction safety and the empirical data available in applying

the Safety, Planning and Control (SPC) model in six construction sites. This paper also provided insight on automation as it supported CSE principles that were discussed in the paper. The overview of the SPC model is shown in Fig. 3.

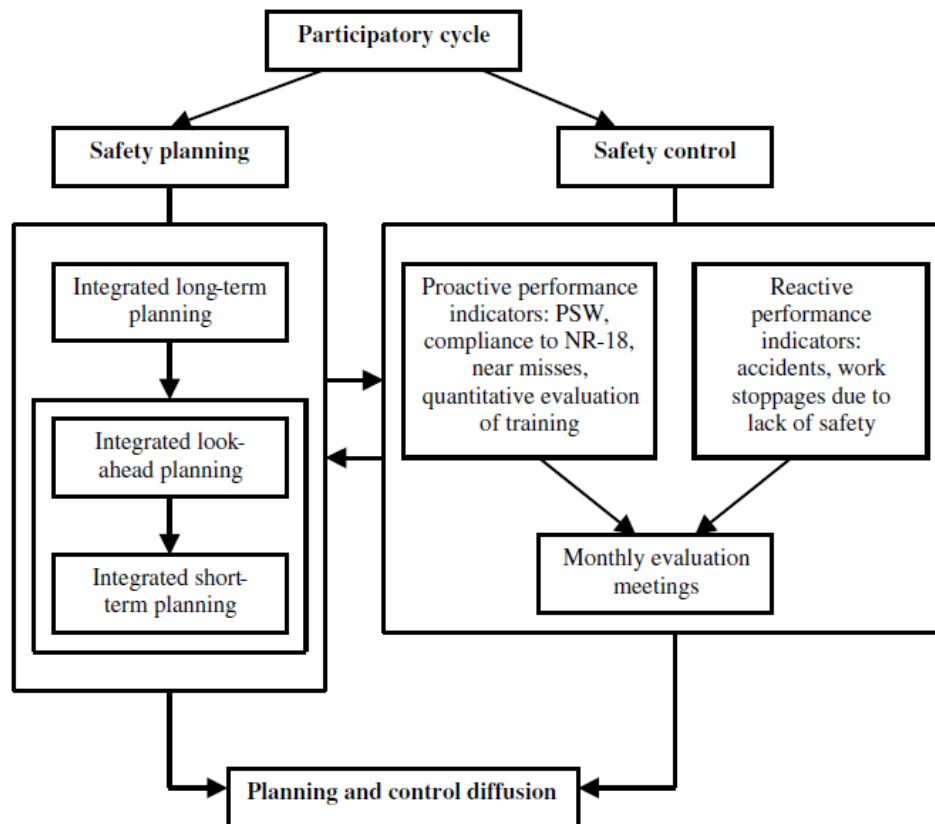


Fig. 3. Overview of the safety, planning and control process. (Saurin. et al. 2008)

2.1 LEAN

The Toyota Production System (TPS) was developed in Japan for the manufacturing industry to compete with the American industry and they devised the lean method to increase their efficiency. The two methods that the TPS was based on are, just-in-time production, and autonomation (Based on Ohno's TPS).

The premise of lean as explained earlier is to minimize or eliminate waste from production systems, operations of services and other business /administration process. The term lean refers to cutting 'fat' out of the production process. In the present construction industry, competition is fierce and lean concepts offer an opportunity to gain a competitive edge in production, services and other applications (Main et.al 2008). Home builders, who used continuous improvement programs, support the theory that safety improves with the use of at least one lean process (Nahmens and Ikuma 2009).

'Kanban' is an operating method for enforcing lean in TPS (Ohno 1978). Kanban provides information in writing regarding, pickup information, transfer information and production information for materials, parts and products. It organizes the movements in manufacturing plant and prevents overproduction. These create a pull and push in the process of production. This can be translated into construction. In just in-time production, a later process goes to an earlier process in the operation flow and withdraws only the number of parts needed, when they are needed. Autonomation refers to a process that may be stopped if any defect is detected and the workers have the

autonomy to seek assistance for the same. Human attention is necessary only when a defect is detected (Ohno 1978).

The lean processes used in lean manufacturing systems are 5S (Set, Shine, Sort, Standardize, Sustain), kanban, kaizen and value stream mapping (VSM). 5S is process oriented and it directs the whole work flow or the system by helping it to identify and eliminate waste. VSM increases the visibility of hidden waste (Main et al. 2008). It also identifies value, waste and flow of material and information. VSM can make construction process more transparent and predictable. This reduces the risk of investment. (Bae and Kim 2008). 5 S denotes the first letters of the phrases that is used to recognize and remove all forms of waste. This can be explained as, Sort: uncluttered the working environment by removing distractions and confusion, Set in order: this increases visibility to find things easily in the work setting, Shine: keep the work place organized and keep the equipments needed in shape with regular checking, Standardize: establish systems to maintain the work place clean and organized, Sustain: continuous improvement along with maintenance of cleanliness and 6S denotes 5S + safety, safety involves minimizing risks in the work place.

Last planner system (LPS) is one of the ways seen to achieve 5S and VSM. It creates an effective process and program. It was developed by Ballard (2000) for the construction industry. LPS involves improvement of construction scheduling and program predictability. It involves communicating effectively and taking responsibility. LPS engages the team members of the project from beginning to schedule and program in collaborative manner. LPS has within itself, sub-processes like make ready design,

push pull system, weekly work plan, and continuous improvement. It also devised a way of validating the whole process if applied to a particular construction project through a method known as the 'Percent Plan Complete' (PPC). This is a measurable way of explaining the percent completion of the project and production deliverables on time (Ballard 2000).

2.2 SAFETY

Nahmens and Ikuma (2009) state that safety has been improved separately from production. Safety cannot be viewed as an afterthought to a construction process as it is an integral part (Nahmens and Ikuma 2009). Organizational pressures to increase productivity and individual workers drive to decrease effort, push workers to work on the edge of safe performance (Mitropoulos et al. 2003). Workers in the building, renovation, demolition and commercial industry in the US suffer a disproportionate share of occupational fatalities and lost-time injuries. Nearly all of the injuries and deaths are preventable. The safety and health problems are tied largely to the construction industry's organization and how the work is performed (Ringgen et al. 1995). Safety depends on the workers, equipment, site, management, administration and materials. Work processes in construction are inherently unsafe owing to the nature of the work performed, this makes safety to be an existent remedy. Therefore safety performance depends on the nature of the job and must be continuously monitored, maintained and improved as a part of those process (Koskela 1992). By understanding the nature of risk and hazard, processes can be planned to minimize safety risks and work places can be less hazardous. Construction project injuries have a tedious task of

overcoming injuries thus importance has to be given to safety program implementation.

In the study by Aksorn and Hadikusumo (2008) the critical success factors were grouped into four categories for safety management. These four being worker involvement, safety prevention, control systems, safety arrangement and management commitment. Koskela (1993) concluded that the implementation of lean production concepts into construction seemed to be a major factor to eliminate accidents. The strategies identified to improve construction safety through lean concepts were

- i.) Designing, controlling and improving engineering and construction processes to ensure predictable material and work flow on site.
- ii.) Improving safety management and planning process themselves to systematically consider hazards and their counter measures
- iii.) Improving safety related behaviors – instituting procedures that aim at minimizing unsafe acts.

Procedures also play a major role in safety management. In fact, production procedures often include alerts on safety hazards into their content. Another frequent approach is to develop specific procedures for safety, through techniques such as preliminary hazard analysis and failure mode and effect analysis.

Based on literature (Ringgen et al. 1995, Mitropoulos et al. 2005) studied some of the safety programs can be identified as follows: comprehensive safety policies, safety committees, safety inductions, new employee trainings, jobsite inspections, accident investigations, first aid programs, in-house safety rules, safety incentive schemes, control of subcontractors, selection of employees, personal protection programs,

emergency preparedness planning, safety related promotions, safety auditing, safety record keeping and job hazard analysis. Workers are the most common cause of accidents when considering behavior models. A zero accident (Liska et al. 1993) workplace that is founded on health and safety increases morale and builds employee loyalty. When an employee is injured, the company loses time and productivity. This results in hiring interim employees and morale drops for the workers. By having minimal accidents the company maintains productivity and morale, causing a decrease in the overall injury rates and the premium rates.

Few of the other safety programs or what is being done in the industry to reduce accidents, reduce costs and add value to the construction process are site safety and health planning and management: a critical element in this aspect would be to assign responsibility for safety and health while at the same time improving coordination among subcontractors and the trades, education and training: which include site orientation and skills which covers topics of rigging trenching etc. are included in the OSHA hazard communication standard. New technologies are coming into places which reduce the risks of accidents, minor, major and other health problems. Examples of these can be seen in wet-blasting, not using asbestos products, using bricklayers that have holes and handles (Ringgen et al. 1995). Federal regulations have incorporated certain regulations that are giving new direction into the construction industry few of them are

- i. Hazardous waste operations and emergency response standard (29 CFR 1926.65)
- ii. Process safety management of highly hazardous chemicals standard
- iii. Lead exposure in construction

Workers compensation law, which permit compensation agreements, higher benefits, care arrangements and alternative dispute resolutions have come into place that reduce time in certain litigation procedures which occur post injury incidents. Other health care deliveries and medical monitoring provide information to workers from the checkups that can be used to improve workplace conditions (Ringgen et al.1995).

3. RESEARCH METHODS

This research is guided through reviewing publications in journals, databases and the Lean Construction Institute website. The objectives of the research, provided insights on lean, safety and the processes they were involved in. Data collected on lean, lean methods and from literature case studies revealed the application of lean in projects in the construction industry. Safety data reviewed in literature, explored the safety programs implemented by the companies and their relationship with the lean methods. A relationship between a lean tool and safety practice was seen to exist when a lean tool and safety practice have a common objective or when the implementation of a lean tool helps to drive the implementation of a safety practice. The relationship was conflicting if the implementation of the lean tool hindered the implementation of the safety objective. Based on the “how-can” approach of deductive reasoning (Popovic and Vasic 2008), the analysis can be done by identifying the overlaps between lean and safety. Deductive reasoning uses a general to specific approach that is found apt for analysis of the theories, moving across from a generalized theory to a specific tool / practice.

Further to strengthen the definition of relationship used in this analysis, a tabulated list of the primary goals or driving factors for each lean tool was deduced. This helped in establishing the relationships between two entities. A framework that relates the lean tools and safety practices selected individually was developed to visually demonstrate the existence of a strong, conflicting or no relationship between the identified lean tools and safety practices. Six case studies of construction firms and

projects that used lean and had a safety implication verified the application of the two theories in use together. Case studies were used as the research questions of “how or why” needed answers (Yin 2009) and the extent of control over the events in construction were minimal or impossible.

3.1 DATA COLLECTION

Data collection is focused on understanding the implications of each lean tool and safety practice. A mixed method of data collection is used to collect the data for the study (Axinn and Pearce 2006). The definitions and explanations of each lean tool were instrumental in guiding the filtration process of where it impacts safety. Common lean methods that were widely used in the industry were selected through literature. These tools were categorized based on the lean project delivery methods (Khanzode et al. 2005) of lean project definition, design, supply, construction and the general tools that are used. The objectives of these tools were studied and they are stated below.

- i. Lean Methods: Performance based contracting (PBC) is used to organize the project delivery methods to accommodate implementing lean or any other innovative methods that is to be used in the construction project in the initial phased of project delivery (Bae and Kim 2008). PBC is a technique that defines the facets of acquisition around the purpose and required performance of facilities (Horman et al.2004). The responsibility of providing information regarding this rests with the specialty contractors or suppliers. This also helps the performance of the project as the main focus of the contract is better performance of the project.

Integrated Project Delivery: It is also known as lean project delivery system that involves project definition, lean design, supply and assembly. It has been used in DPR Construction in their healthcare project as quoted by Dean Reed (2005). Integrated project delivery also maximizes the collaboration among the stakeholders involved in the project from the early phases. Integrated project delivery (IPD) binds the stakeholders in a single contract of the IPD team and the primary team members are responsible for the prime contract. This facilitates increased communication, quick decision making in the team towards the betterment of the project.

Integrated Design: This is a design phase in the initial phase of the project where the stakeholders are involved in the decision making of using different synergies of construction techniques and the process that are expected to be involved in the construction project. (For e.g. decisions related to using lean, sustainability and building information modeling.) It is the decision of the stakeholders involved in the project to adopt this method in the project delivery process (Bae and Kim 2008).

Target Costing: The financial impacts on the project are tracked using this tool. It states that the building should be built within the budget specified (Ballard 2006). Implementation of target costing is practiced by allocating the larger amount of the budget for the sub phases of functions of a facility. This helps in detecting variability in a budget and contingencies. The team responsible for realizing this expectations comprise of the architect, owner, contractor, specialty contractors and functional agents (Bae and Kim 2008). The customer's interests are protected in the sector of finances if target costing is achieved successfully.

Poka-yoke: It is a tool to make any process error-proof, or error tolerant (Rasmussen et al. 1994) this works within the objectives of safe work systems and lean. Poka-yokes take the form of safeguards and personal protective equipment, these have wide set of functions (Saurin et al. 2006). The management in charge of the project takes responsibility. Rules and regulations prescribed by the state/federal agencies also complement the tool. It could be incorporated at all phases of the project as per the needs of the processes. Just- in-time: As the nomenclature states, it is the concept of having the right amount of product at the right time, in the right place. Just-in-time reduces the potential damage to inventory and the consumption of material. (Riley et al. 2005). Contractors can save inventory costs as the inventory levels are reduced. This is implemented essentially in the supply phase where material requirements increase prior to / during construction process. Prefabrication is a technique where the components required for construction are assembled/manufactured off-site and transported to site for the final assembly (Toole and Gambatese 2007). This in terms of lean provides speedy construction phases and eliminates waste out of the process and materials. Better manageability, reduction of overall lifecycle costs are among the features of using prefabrication. The contractors and owners have to be decisive regarding the approach to be used in prefabrication techniques during construction/prior to construction. The design has to complement the prefabrication process.

Value Stream Mapping: It is a lean production philosophy that detects hidden waste in a project as the process of completion of a task during construction can be mapped (Main et al. 2008). This helps in detecting the errors that cause waste. It is an

asset to detect waste in reference to time, resources. It is the responsibility of the contractor or the project manager to record the process and take action to add value to the construction project.

Kaizen: It means continuous improvement in a work process/task. Kaizens are characterized as short periods of intense activity driven toward resolving a specific problem or achieving a specific goal in a short period of time (Bae and Kim 2008). It is one of the primary ways to implement lean in the construction phase. The contractor or the owner involved is responsible for making the process of building a value added process. **Kaikaku:** It targets rapid process improvement. It is designed to eliminate waste and make rapid changes for product and process improvement in workplace. This unites the workforce from different strata of organizational level, addresses problems and improves processes (Bae and Kim 2008). **Last planner system™:** Introduced by Ballard (2000) shows improvements in the cost, schedule, quality and safety aspects of a construction project simultaneously. Last planner system involves planning, estimating and scheduling of a construction project. Having weekly schedules and look ahead schedules simplifies the schedule and makes the people in charge accountable. The validity for this method can be based on a method known as “Percent Plan Complete” that measures the percent of work completed.

Visual Management: This approach of lean production detects deviations from standards. Visual devices are always adopted in the construction process to increase the safety among the workers. Visual communication is targeting a wide range of users. It is

used on site by putting up banners and other visual aid signs for the employees to follow (Saurin et al. 2006).

5S: It is expanded as Set, Sort, Shine, Standardize and Sustain. Another 'S' is added in the present scenario that includes 'safety'. 5S mechanisms overall help in the house keeping aspect of the construction. This may help a contractor increase productivity while protecting laborers from hazards, injuries by providing clean and accident free work areas (Bae and Kim 2008). The objectives of 5S is to improve profits, management and achieve a safe jobsite.

Autonomation: Shingo (1986), Filho et al. (2007) suggested that during a manufacturing process the operators or the machines have to be provided with the autonomy to stop production whenever something abnormal is detected. It can be translated into construction as well. This method would call for immediate action by the project manager /engineer/ superintendent as to the further course of the project. In the long-term, companies that apply this principle would have lesser hindrances than companies that did not apply it (Womack et al. 1990).

ii. Safety Programs

For the framework the safety programs or practices that were collected were based on hierarchical application levels, the organizational level practices that are standardized across the organization for all their projects, these involve techniques such as poka-yokes, incentive programs etc. On a project level the accident prevention techniques, job hazard analysis would be examples. As a worker, he/she takes few

precautions and reaches out to other workers on site. These tools were compared against the lean tools and the inter-relations were found.

Accident Predictive Techniques (APT): Accident predictive technique is safety program which motivates the worker to identify a possible hazard by analyzing his work practices. The main purpose of APT is to habituate hazard recognition and eliminate errors which can lead to incidents. An APT report consisting of the description of the hazard identified and its recommended corrective action is reviewed by the work team in the department's sequential safety meetings (Air Products 2002). APT's can be applied to all phases of construction where the worker is responsible for the safety of his work practices. APT's lends a predictive tool to the safety management system, permeating through the worker level processes involved in construction.

Safety Sampling / Inspection: Safety Sampling is a safety technique which uses observational skills of an experienced worker to monitor a set of workers and enumerate their at-risk and safe work practices. This method leverages the expertise of the personnel who are familiar with the work process under study and are well trained in identifying hazards. (Manuele 2003). Feedback is given to the concerned individual performing the at-risk process and the observations are submitted as a report for further analysis. Generally, the sampling is conducted by the people in the leadership team who are the well trained members of the workforce (Air products 2002).

Worker Shielding / Personal Protective Equipment (PPE): This safety program is enforced by the management to make sure that the workers are safe from hazards which cannot be eliminated and focus on worker health (Landsberigs et al. 1999). Hard Hats,

protective glasses are a few examples of this program. Workers handling hazardous chemicals are trained to shield themselves before the accident occurs (Air Products 2001/2002). This is a very common safety program across various construction companies and it is a mandatory investment from the management's perspective.

Safety Metrics: Safety Metrics form an integral part of the safety management system. The management reviews performance metrics along with the safety metrics of the construction project. This forms an important feedback process of the safety system of the construction firm. Safety metrics are classified as reactive and proactive measure of safety (Hinze and Godfrey 2003). Incident rates, a reactive measure is a common safety metric which helps the firm establish the credibility of its safety program. Near misses, on the other hand are regarded as a proactive measure of safety.

Accident Sequence Guide: Accident Sequence Guide is designed to analyze how accidents occur and determine its severity (Air Products 2002). The sequence guide helps the management to understand sequence of steps of a worker violating an accident prevention measure to the incident being classified as a near miss or an injury. This program is a proactive step taken by the management to ensure proper analysis of possible hazards within the construction zone.

Accident Investigations / Root Cause Analysis: is an important technique to help management understand the causes for an incident and suggest preventive measures for the future (Boldt 2001). This practice provides feedback to the construction workflow and prevents similar incidents to happen in the future. The management constitutes a team of well experienced personnel to perform an accident investigation. Thus, this

program measures the ability of the management to take responsibility of the incident and design a corrective procedure.

Site / Job Hazard Analysis: Site hazard analysis is a safety program which evaluates the construction site for safety performance and helps identify possible hazards. The safety team evaluates factors affecting site safety. A Site safety plan is developed and submitted to the management as a part of the analysis (Mohamed 2002). Job Hazard Analysis identifies hazards within the construction of a particular task where workers within various teams utilize the same construction site. This proactive analysis predicts the risks for a particular task in a dynamic work environment surrounding the activity under analysis. The Analysis is performed by the safety team associated with the project and a report is submitted to safety lead to take prevention measures for the hazards identified. (Popovic and Vasic 2008)

Training (OSHA/IFE/FIRST AID): Training educates the workers on the importance on safety and helps them to deal with incidents at site. Safety training provides the means for making accidents more predictable (Vredenburg 2002). The safety team is responsible for conducting training across the workers in the construction firm. Training is also seen as a proactive safety measure to enable workers to handle unforeseen hazards.

Daily Pre-task Safety Planning: Pre-Task planning safety planning consists of a worksheet which enumerates general aspects of a task which helps the worker identify hazards before the task is performed. Pre task Planning is also known as Pre Task

Analysis (PTA). PTA helps identify all the hazards associated with a task and recommend for eliminating and controlling these hazards (Walbridge Aldinger 2002).

Safety Incentive Program: Safety incentive program is initiated by the management as a proactive measure to rapidly identify hazards as they get noticed. The incentives act as a motivating factor for the workers concerned to identify and report possible hazards to the safety team. It reinforces the identification of a hazard or an unsafe act which would have resulted in an accident while giving incentives. It generally runs along with a safety education and the training program (Vredenburg 2002).

Safety Alerts / STOP Program: Safety alerts is practiced as a precautionary measure by workers who have had a near miss or identified a possible hazard. The STOP program is an abbreviation of See, Train, Observation, and Program, which motivates the workers to use their observation skills and use their training experience to identify possible hazards in their work practices.

Material Safety Data Sheets: Material safety data sheets is a safety measure which help the worker handling the chemical to be aware of the risks of the task. The data sheets educate the worker on proper handling and disposal of the chemical.

Safety Orientation: Safety Orientation sessions are conducted by the safety team or senior management to educate the inexperienced new workers of the common hazards at a construction site. The orientation also trains the new workforce to handle common accidents that can occur in the construction site due to unforeseen circumstances.

Record Keeping / Logs: Records keeping is a traditional safety practice with an objective of storing critical project information which might become useful for further

safety analysis. Most of the data for accident investigations are taken from these records for further analysis.

Litigation: Litigation is an important process undertaken by the management to provide aid to the victims of an accident. Safety teams and management coordinate to develop the structure of the litigation program.

3.2 DATA ANALYSIS

Based on the data retrieved from literature, a reasoning that relates both theories was necessary. To relate the theories and deduce an implication, deductive reasoning was used as explained by Popovic and Vasic (2008). The term deductive reasoning technique is a form of logic and reasoning. The logical process draws conclusion from a set of premises and contains collective information on the premises (Popovic and Vasic 2008). The analysis characteristics of deductive reasoning are based on a set of parameters that question the premise on ‘how-can’ – which explains how a lean method can have an implication on the safety practice. This form of analysis moves from a larger scale to specific cases. This is possible after the nature of the element in scrutiny is identified.

This research culminates into the fourteen lean methods that have been selected and a specific safety impact of each lean method has been studied in detail. These explanations were explored based on a time factor in the lean project delivery system. With lean project definition, design, supply, construction and the general methods the methods were categorized based on which phase they provide the maximum impact on. Along with this study it was also implied through literature that, each lean method had a

specific driving factor. This was developed into a table that showed each lean method against the objective or driving factor. Table 1. represents the driving factor that was deduced for each lean method objectives that was selected. Performance based contracting was specific to performance and a contract that was measured on the performance of a project or process. Project delivery integration was necessary to eliminate information dissemination among the various teams hence it is communication driven. Integrated design involved all stakeholders from the phase of project initiation thus providing better design strategies. Target costing is a means to work within a stipulated budget and essentially is economics motivated. Poka yoke is a failsafe mechanism adapted in many industries along with construction. Just in time concentrates on the inventory and safety stocks. Flexibility is provided through pre-fabrication. Value stream mapping makes the process transparent that helps in identifying hidden waste. Kaizen and Kaikaku are improvement driven; they focus on continuous and rapid improvement respectively. Ballard's (2000) last planner system™ works on a schedule immediate and long-term and validates the performance through percent plan complete. Visual management provides effective signage in the jobsite and 5S enhances housekeeping. Autonomation equips the worker with the autonomy to decide when to halt a process and seek assistance.

Understanding the driving factors for each method, help in relating safety and lean. This also helps in identifying the intersections with strong and conflicting impacts. The safety impact of each lean method can be analyzed based on the driving factor.

Based time factor of ‘when’ in the lean project delivery phases each method has been explored.

Lean Project Definition - Performance based contracting impacts safety positively in defining a safety metrics as performance is a measure of metrics. Training, pre-task planning and orientation also are productive. It reduces waste, thus reducing incidents in wasteful processes. Innovative technologies can be used in safety planning, training etc. The performance is an indicator and helps decide the incentives or policies that are to be implemented.

Table 1. Exploration of lean methods objectives.

Sl.No.	LEAN METHODS	DRIVING FACTOR
1.	Performance Based Contracting	Performance
2.	Integrated Project Delivery	Communication
3.	Integrated Design	Design
4.	Target Costing	Economics
5.	Poka Yoke	Errors
6.	Just In Time	Inventory
7.	Prefabrication	Flexibility
8.	Value Stream Mapping	Process
9.	Kaizen	Continuous Improvement
10.	Kaikaku	Rapid Improvement
11.	Last Planner System	Schedule
12.	Visual Management	Visual Aid
13.	5S	Housekeeping
14.	Autonomation	Autonomy

Integrated project delivery puts all stake holders on the same page. They share the risks and profit of project performance. Decision making is enhanced regarding practices and risks owing to effective communication amongst the teams.

Lean Design – Integrated design of a safety system involves trade-offs. Safety requirements may conflict with other requirements that like material availability, performance. The identification of safety conflicts within a construction process and solving them could be the centre focus of a design process. Thus integrated design helps in setting priorities for a process to make it a safer. (Becker 2009)

Target costing strategy makes planning more crucial as a result of which there could be times when safety is a compromised factor. Therefore it increases the risk.

Poka yoke contributes to make boundaries of performance error-tolerant, which is a major principle both of safe work system design and also of lean production. (Rasmussen et al. 1994).

Lean Supply – Just in time provides the right amount of material and resources needed at the right time, this removes the idea of safety stock (Ballard and Howell 2003). By following just in time there is a reduction of waste and variations. But on the contrary there is also an increase of risk due to uncertainty of resources and also increased amount of transportation.

Lean Construction – Prefabrication provides safer work conditions as processes are standardized and automated. The site or the task is easily manageable as it is divided by small bits. This in turn provides better work conditions.

Value stream mapping makes process more predictable and transparent. This eliminates risk and increases value by enhancing safety in the work environment. It is easy to indentify unsafe work environment around a process.

Kaizen programs reduces opportunities for accidents through reduced waste in material motions and processes steps, therefore reduces safety hazards. Kaizen programs include safety initiatives as one category of improvement projects undertaken

General Methods – Kaikaku is a rapid improvement process, there are times when safety aspects are overlooked. Through this radical change process it is possible to identify the risk. It syncs with value stream mapping, but Kaikaku applies to a larger interface therefore safety measures taken through these impacts over a longer period of time. Last planner system TM increases predictability of the project by inventing task based scheduling. This has immediate and long term goals for the project owing to this the work environment is stabilized. Look –ahead schedules prepares for an estimated risk. Visual management applies to safety in signage, demarcations, barricades, boards, ramps all the measures that are taken on site to visually instruct the worker to prevent accidents. There are also record logs or sign boards where the accident rates are posted which are an indicator of safe performance. Contrastingly a hazard cannot be recognized if there are not physically visible in nature.

5S cleaning and maintaining the workspace by sorting, organizing items reduces risk of accidents from trips and falls. Having a specific place for storage provides through clarity. Timely cleaning also makes the equipment related safety problems visible immediately. Standardizing processes translates to a clear safety program.

Sustaining includes safety inspections and audits in order to maintain a safe work environment.

Autonomation implies to safety where a process can be put to halt before any accident or mis-hap occurs. It provides the autonomy to identify the risk and take measures. Thus all these lean methods actively identify safety as a necessity in the process of construction and also pave way for a better work environment if both are implemented concurrently. Table 2. summarizes the safety impacts of the lean methods that were studied and explained in this chapter based on the classification of the lean project delivery systems. This summary is explains the impacts of lean tools on safety and how safety either benefits/conflicts with the lean method if used.

Table 2. Safety impact of lean methods during lean project delivery phases.

LEAN PROJECT DELIVERY PHASES	LEAN METHODS	SAFETY IMPACTS
Lean Project Definition	Performance Based Contracting	<ul style="list-style-type: none"> ▪ Innovates safety planning ▪ Motivates Safety metrics ▪ Provides a better framework for safety related incentives
	Integrated Project Delivery	<ul style="list-style-type: none"> ▪ Enhanced communication helps establish uniform safety standards ▪ Coordinates for risk management ▪ Faster decision making
Lean Design	Integrated Design	<ul style="list-style-type: none"> ▪ Integrates safety in design ▪ Identifies safety-design conflicts ▪ Sets safety standards early
	Target Costing	<ul style="list-style-type: none"> ▪ Increases risk as economic objective gain priority ▪ Allocates safety budget within the target constraints
	Poka Yoke	<ul style="list-style-type: none"> ▪ Develops error proof processes ▪ Prevents incidents before hand ▪ Results in a safe work environment
Lean Supply	Just In Time	<ul style="list-style-type: none"> ▪ Reduced excess inventory at site ▪ Increases risk by narrow time window for delivery
Lean Construction	Prefabrication	<ul style="list-style-type: none"> ▪ Applies use of automation ▪ Eases management by creating smaller tasks ▪ Standardizes safety practices
	Value Stream Mapping	<ul style="list-style-type: none"> ▪ Processes are transparent ▪ Identifies risk within a process ▪ Recognizes hazards

Table 2, Continued

LEAN PROJECT DELIVERY PHASES	LEAN METHODS	SAFETY IMPACTS
	Kaizen	<ul style="list-style-type: none"> ▪ Sustains safety by continuous improvement ▪ Safety team collaborates with other teams ▪ Focuses on safety metrics ▪ Innovates safety initiatives
General Tools	Kaikaku	<ul style="list-style-type: none"> ▪ Rapid improvement increases the need to collaborate with the safety team ▪ Increases risk by shifting orientation to financial objectives
	Last Planner System	<ul style="list-style-type: none"> ▪ Schedules processes , defines relation ▪ Encourages task based safety planning ▪ helps risk estimation ▪ Stabilizes safe work environment
	Visual Management	<ul style="list-style-type: none"> ▪ Communicates safety information effectively ▪ Recognizes hazards ▪ Eliminates repetitive errors
	5S	<ul style="list-style-type: none"> ▪ Enforces equipment and work area safety by efficient housekeeping ▪ Standardizes safety by organizing item within a workspace ▪ Decreases risk of hazards
	Autonomation	<ul style="list-style-type: none"> ▪ Identifies and stop unsafe work practices ▪ Enhances visibility of safe work practices

3.3 DATA INTERPRETATION

Based on the literature reviewed and analyzed data was interpreted in a way where a relationship between the two theories were being formed. The lean methods and safety programs have a strong relation, conflicting relation or no relation. A strong relation ties the two theories and expresses that if used they work in synergy. A relation is seen as a strong one when a lean method if used suggests betterment in a safety practice. Compromised correlation expresses that there is no symbiotic relationship between the tools at present; this could be owing to properties of one of the theories.

Safety metrics plays an important role in the quantifying the performance of contractors. Metrics related to safety also contribute towards the performance and hence can be instrumental in obtaining contracts with firms practicing performance based contracting (PBC). Thus, the role of safety metrics is enhanced by the implementation of PBC. These metrics also helps drive other safety mechanisms like training, task-based safety planning, safety orientation & record keeping. The management will encourage safe work practices from contractors by introducing a safety incentive program. Thus PBC helps drive these safety mechanisms which lead to safe lean work environment. On the contrary, PBC hinders the progress of accident investigations as the construction activities are monitored by the contractors. However, litigation costs associated with incidents are generally covered by contractors which eases out financial strain associated with incidents.

The main idea behind integrated project delivery (IPD) is forming a core team which will result in better communication between the stakeholders of the construction

project. The IPD team has authority to ensure uniform compliance of safety procedures (Matthews and Howell 2005). Enhanced communication aids in accident investigations and safety analysis of job/site involved. The Safety incentive program can be uniformly applied across all stages of construction through the IPD team. Moreover, Safety programs like safety alerts/STOP and safety orientation can leverage the communication power of the core team and help in ensuring safe work environment.

Knowledge about safety can be leveraged in the design phase of the construction project (Hasan et al., 2003). Integrated Design (ID) helps in developing this synergy in the design phases of the project. The Overall process of safety analysis is aided by this synergy. Further, the safety incentive program can be tuned to facilitate the integration. Designers can take part in safety orientation and several hazards which develop due to an incorrect design method can be removed at an early stage. ID also helps in developing material safety data sheets which is instrumental in increasing awareness about the material.

Target Costing has a conflicting impact on the safety incentive program. Target costing is a rigid constraint for every construction project with which all safety mechanism has to comply.

Safety Poka-Yokes prevent errors in the construction process. The central idea is to avoid hazards by developing error prevention techniques. Poka-yokes can be devised to either prevent accidents or react to the consequences of errors. (Saurin et al., 2008). Thus many safety mechanisms can develop error-proofing techniques to ensure a safe

working environment. Safety orientations can include demonstrations of Poka-yoke to help new worker understand the value of error proofed work practices.

Just in time systems reduce inventory in the construction site. Lower inventory eases the manageability of tasks which facilitates the safety analysis process and pre-task safety planning. Although, Koukoulaki, (2009) argues that systems like just in time increase material handling due to a narrow window for service or delivery. This leads to increased chances of incidents and undermines the effect of accident preventive techniques.

The advantage of prefabrication lies in the fact that the task are broken down into easier manageable tasks. This has a positive effect on safety mechanisms which work on the idea of hazard recognition. Bae and Kim (2008), state that prefabrication leads to overall safer working conditions.

Value stream mapping (VSM) shares the main idea of identifying value and hazards with many safety mechanisms and help facilitate their implementation. VSM identifies processes which safety mechanisms like safety analysis can leverage for easier implementation.

Kaizen and safety are regarded as two sides of the same coin. Kaizen, being a continuous improvement procedure can be easily leveraged to facilitate implementations of any safety mechanism. Safety Kaizen teams are involved in developing strategies to leverage improvement in implementing safe work practices across the construction site.

On the contrary, Kaikaku focus on rapid improvement in processes and work practices with economic objectives. This has detrimental effects to the many safety

mechanisms. It is generally found that safety objectives and economic objectives are in conflict with one another. Thus, without the presence of Safety personnel in team involved in rapid improvement, the lean method can have negative impacts on safety mechanisms (Bae and Kim 2008).

The Last planner system focus in scheduling activities requires for the completion of a task. This aids in implementation of many safety mechanisms which are task based.

Visual Management's central idea lies in the observation skills of the worker and trained personnel on site. Many of the safety methods also rely on observation skills on the personnel involved.

5S's main objective focuses on workplace management. An efficient workplace management enforces a safer environment as the work practices are more manageable and easier to perform. It also helps in identifying possible dangers in the surrounding workplace. Thus it helps in indirectly implementing most of the safety mechanisms.

Autonomation shares its objective with the concept of STOP program and safety alerts. This enforces better safer work environment as each unsafe work practice is identified and a remedy is developed before proceeding with the construction. Most of the safety mechanisms which rely on hazard recognition are aided by the implementation of autonomation.

3.4 CASE STUDIES REVIEWED

Case studies of companies that used lean tools and expressed that they had a safety implication were identified through literature. These case studies provided a

significant verification regarding the lean methods that were applied in their projects or that were being used in the company, if there was a safety impact those were stated.

These case studies summarize the lean methods used by the project, the benefits of these lean methods and safety impacts.

a) Autodesk Inc. AEC Solutions division headquarters, Waltham MA (2009)

This case study features in the American Institute of Architects report by Cohen describing the successful implementation of integrated project delivery in this construction projects. Risk and reward were shared among the core team members, architects and builder through incentive compensation layer. The integrated team was able to communicate through the length of the construction and it helped faster decision making.

- Lean tools used: Integrated Project Delivery
- Benefits: Faster decision making through an integrated core team
- Safety impacts: Risk and reward is shared through an incentive program

b) Office development project in UK

Johansen and Porter (2003) study the experience of introducing last planner into a UK construction project and describe its impact. Rework was reduced significantly due to the implementations and hence it helped in reducing 'over run' time.

- Lean tools used: Last planner
- Benefits: Reduced rework
- Safety impacts: Lower risk due to reduced waste

c) Implementing lean construction in MT Hojgaard

Thomassen et. al. (2003) reviews the implementation of lean construction in MT
Hojgaard, a large Danish construction firm. The findings of this case study, states that it is 95% certain that accident rates are lower for projects using lean tools as compared to project which does not use lean. The last planner system and the look ahead schedules are extensively used in its projects. It is suggested that lean principles should be used in the design phase of the project.

- Lean tools used: Last planner, integrated design
 - Benefits: Lower disruption of work, lower accident rates
 - Safety impacts: 95% chances of lower accidents in lean construction projects
- d) Implementation of Lean construction in Messer (Oak Ridge High School Construction)

Messer utilizes lean construction principles in its projects as they realize that strategies and communication are its two main benefits. Reduced stress, Reduced re work, less project chaos and more predictability in projects were defined to be key learnings.

- Lean tools used: Last planner system, Visual management, Poka-yoke, continuous improvement
- Benefits: Less chaos, more predictability
- Safety impact: Increased awareness and training about work practices

e) DPR Construction - Camino Medical Center

The lean design workshop held by DPR illustrates the used of lean tools to help facilitate faster design and developing safe work practices. A core group of the owner, architect and the contractor was formed as the integrated project delivery team. This team found

that the implementation of the Last planner system results in reliable workflow as the knowledge of the foreman is utilized in the design. Hence, quality becomes the responsibility of all the stakeholders in the project.

- Lean tools used: Kaizen, Value Stream Mapping, Last Planner, Integrated Project Delivery (IPD), Integrated Design
- Benefits: Greater collective understanding, reliable workflow, efficient sequence of design work
- Safety Impact: IPD team monitors safety in design, safe work practices, look ahead schedule aids establishing safety standards

	SAFETY PROGRAMS															
	Accident Predictive Techniques	Safety Sampling / Inspection	Worker Shielding / PPE	Safety Metrics	Accident Sequence Guide	Accident investigations / Root Cause analysis	Site/Job Hazard Analysis	Safety Signs	Training (OSHA/ IFE/ FIRST AID)	Daily pre-task safety planning	Safety incentive program	Safety Alerts / STOP Program	Material Safety Data Sheet	Safety Orientation	Record Keeping / Logs	Litigation
LEAN TOOLS																
PERFORMANCE BASED CONTRACTING																
INTEGRATED PROJECT DELIVERY																
INTEGRATED DESIGN																
TARGET COSTING																
POKE-YOKE																
JUST IN TIME																
PREFABRICATION																
VALUE STREAM MAPPING																
KAIZEN																
KAIKAKU																
LAST PLANNER SYSTEM																
VISUAL MANAGEMENT																
5S																
AUTONOMATION																

Fig. 4. Framework showing the relationship of the lean methods and safety programs.

■ No impact ■ Strong ■ Conflicting

Fig. 4. represents the relationship framework between lean methods and safety programs, the red box in the figure represent a strong impact of the lean method on the safety program. A grey box indicates a conflicting impact of the lean method on the safety program. The blue box represents that there is no impact of the lean method on the safety programs.

4. FINDINGS

Inferring from the analysis and interpretation of the two theories, it is seen that the lean methods impact the safety programs strongly by 54.91 %. This is represented in the Fig. 4. by the red boxes. It is also seen that the lean methods have 7.6 % conflicting impact on the safety program. Fig. 5. represents a chart showing the relationship framework percentage breakdown of the impacts. Thus the framework is indicative of the synergy between lean and safety.

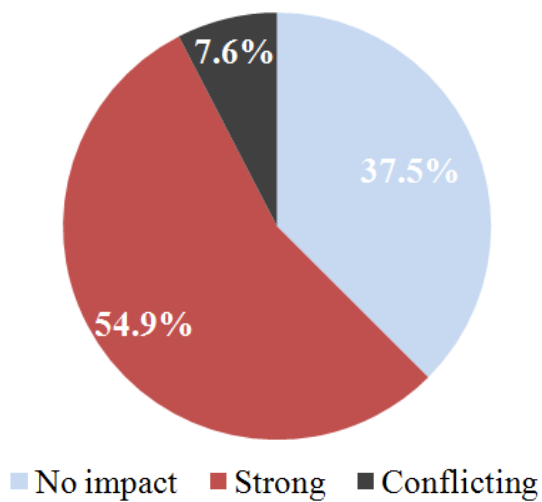


Fig.5. Chart showing the relationship framework percentage breakdown.

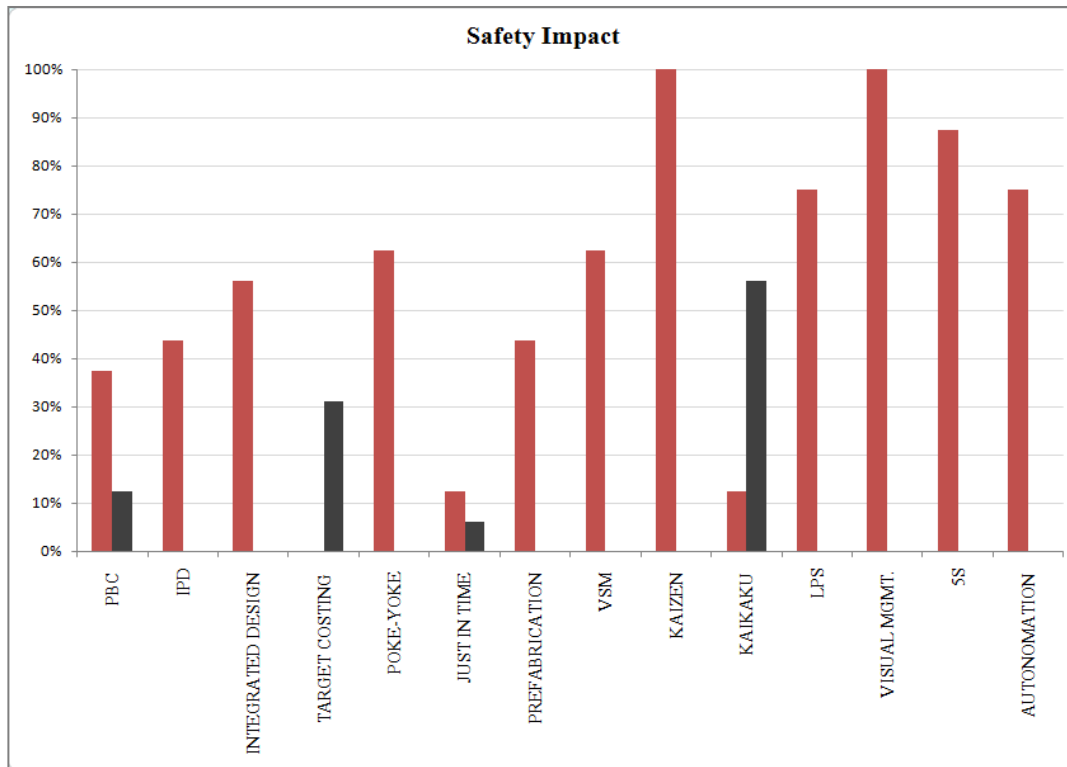


Fig.6. Safety impact.

■ No impact ■ Strong ■ Conflicting

Fig. 6. shows the impact of the respective lean methods on the safety programs. Here it is noted that lean method like kaizen, 5S and visual management have the most impact on safety. Lean method like Kaikaku and target costing have a conflicting impact on the safety programs

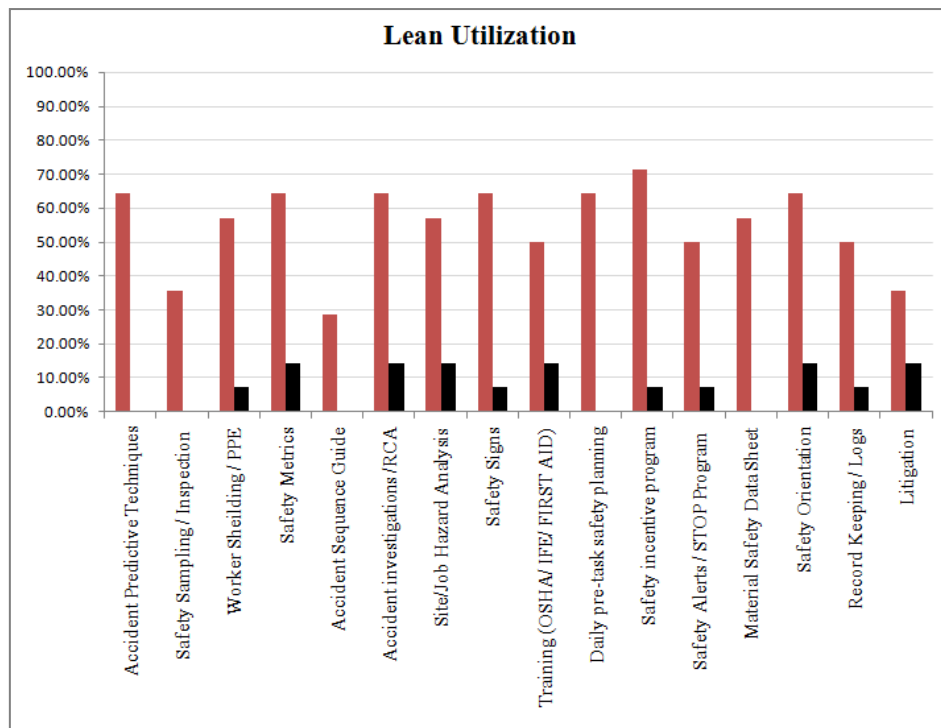


Fig.7. Lean utilization.

■ No impact ■ Strong ■ Conflicting

Fig. 7 explains the utilization of lean methods on the safety methods it is seen that the safety incentive program makes the maximum use of the lean methods. Programs like accident predictive techniques, safety metrics, accident investigation / root cause analysis, and daily pre-task planning, and safety incentive program and orientation utilize lean for over 60%. Conflicting impact is less than 15 % for safety programs such as PPE, safety metrics, root cause analysis etc.

5. CONCLUSIONS

5.1 CONCLUSIONS

It has been identified through literature that a relationship can be established between the lean methods and safety programs. Lean methods add value and eliminate waste and safety helps in risk mitigation. Thus, it's widely evident that lean and safety have synergy which can be harnessed to create a safe productive workplace. The principle of lean and safety are aligned and the construction industry can benefit by their integration. Research methods involved in this thesis extracts data of lean tools and safety practices through literature and case studies.

Deductive reasoning has been used as a data analysis technique to establish a relationship between the identified lean tools and safety practices. Deductive reasoning defines the cause and effect of each principle. The framework was drawn to facilitate the interpretation of the data collected and visually depict the relationships established. The tools and practices used in the construction industry present an overlap conceptually which is the major advantage of deductive reasoning.

The major finding of this research is that there is 54.9% strong impact of lean tools studied on the safety practices reviewed. It was also found that there is a 7.9% of conflicting impact of lean tools on the safety practices studied. Kaizen, 5S, visual management and autonomation was found to have a maximum conceptual overlap with safety practices. Overall the safety practices benefited evenly from the usage of lean tools.

These findings can be utilized to implement the lean tools which will correspond with the safety practices enforced by the construction company. Lean tools can be implemented easily to support safety practices.

The limitation of this research lies in qualitative findings from the data collected. A quantitative analysis involving the documentation of project process and safety data would further strengthen the relationships identified. On the contrary, a quantitative approach would not provide a perspective on a larger scale. The bench mark to compare projects and tools/practices used in them will never be totally constant owing to the dynamic nature of the construction industry.

5.2 FUTURE WORK

Further research can be done on the specific relationships identified and case studies can be conducted to measure the impact of a lean tool to a safety practice. Future work can include case studies which validate this study on a company or project basis. Relations can be found at an implementation level with a quantitative approach to back the findings of this paper.

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